International Journal of Applied Earth Observation and Geoinformation 45 (2016) 42–54

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Disturbance analyses of forests and grasslands with MODIS and Landsat in New Zealand

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ARTICLE INFO

Article history:
Received 21 May 2015
Received in revised form 12 October 2015
Accepted 15 October 2015
Available online 12 November 2015

Keywords:
MODIS
Landsat
Tasseled Cap
Forests
Grasslands

ABSTRACT

In this study we present, evaluate and validate an approach to monitor forest and grassland disturbance. We apply the approach to both Landsat and MODIS imagery for the North Island of New Zealand and validate the results based on high resolution OrbView and Ikonos imagery. We found an overall accuracy of the disturbance index of 98% for the two studied land cover types. The kappa value was 0.770 indicating a 77% better agreement than what would have occurred by chance. We found that there is a difference between the accuracy received for grassland areas compared to the accuracy received for forest areas, with the grassland areas outperforming the forest areas (Kappa of 0.855 vs. 0.656). We split the validation results by soil type and also evaluate the effect of different soil types with respect to grazing pressures. The disturbance index behaved consistently for all available soil orders.

We found forest disturbance for approximately 36.2% of the exotic forests, resulting in an annual clearing rate of 2.6% of the forest over the study period. Lastly we present a close-up study to evaluate the changes in grazing in one intensely used catchment. We demonstrate that the December/January disturbance rates have increased from about 6% in 2000 to about 16% in 2012.

1. Introduction

Grassland ecosystems cover approximately 37% percent of the earth's terrestrial area (O'Mara, 2012), and about 25% of global ice-free land area is grazed using a wide range of management practices and stocking rates (Schipper et al., 2014). Some estimate that the global carbon stock in grasslands is about 50% more than the amount stored in forests globally and grasslands are continuing to sequester carbon (Lal, 2004; O'Mara, 2012). However, many of the global grassland ecosystems are in poor condition; the Land Degradation Assessments in Drylands (LADA) found that approximately 16% of the grasslands are currently undergoing degradation (Conant, 2010). Most of the problems result from overgrazing, leading to soil erosion, weed encroachment and changes in soil organic matter (McSherry and Ritchie 2013; O'Mara 2012). Indeed, grazing land management and pasture improvement was proposed as one of the technical climate change mitigation options (Smith et al., 2008). However, managing grazing intensities is further complicated by the fact that both under- and over-grazing can result in carbon loss from soils and result in lower carbon sequestration (O'Mara 2012).

While high intensity grazing lands have been undergoing tremendous changes, they are less often studied than production forest ecosystems or high intensity croplands, and as a result, there is far less information on the type and amount of change that is occurring in these ecosystems (Pearson, 1997; Weeks et al., 2012 White et al., 2000). One nation that is currently experiencing intense and broad-scale changes in their grassland ecosystems is New Zealand. About 60% of the terrestrial ecosystems of New Zealand are grasslands, with a combination of introduced and indigenous grassland species (Wardle, 1991; Weeks et al., 2013b). As a result of increasing demand and consequently high payouts for dairy products, New Zealand's grazing practices have intensified over the last decade, resulting in a 40% increase in milk production between 2000 and 2010 (O'Mara, 2012) and a 24% growth in the dairy herd between 1996 and 2006 (Ministry for the Environment 2007). Between 2008 and 2012, the number of dairy cattle increased by another 1.1 million, from 5.3 million to 6.4 million (Statistics New Zealand, 2012). To increase profitability, national average stocking rates have increased from 2.1 cows/ha in 1982/83 to 2.85 cows/ha in 2012//13 (DairyNZ, 2013). In addi-

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http://dx.doi.org/10.1016/j.jag.2015.10.009
0303-2434/

tion, over the last three decades large plantation forests were planted with exotic species (largely Pinus Radiata) at the expense of grasslands. These plantation forests now cover about 1.8 Mha of New Zealand (Kirschbaum et al., 2011), although between 2002 and 2007, about 50,000 ha of newly planted forests were reverted back to dairy farming (Hewitt et al., 2012). Thus, while the size of pastures decreased, livestock densities and production increased considerably. This type of production increase has only been possible as a result of the introduction of non-native grasses and the conversion of indigenous grasslands into productive lands which are better suited to intensive grazing practices (Weeks et al., 2013b).

To understand the effect of these land management practices and to evaluate the condition of New Zealand's grasslands, spatially explicit information is very important (Weeks et al., 2013a). However, some studies have shown that it is difficult to distinguish between the different grassland cover types in New Zealand with remotely sensed observations (Vescovo et al., 2009; Weeks et al., 2013a). Besides changes in the extent and management of grasslands, forest clearance is still ongoing as well, with 51,000 ha of indigenous forests cleared between 1990 and 2008 (Dymond et al., 2012).

Forest disturbance detection is a regularly studied field and Landsat and MODIS are often used sensors (Healey et al. 2005; Hilker et al. 2009; Masek et al. 2015; Townsend et al. 2009; Tran et al. 2016). Extensive studies have been done evaluating American forest cover changes with Landsat and MODIS based disturbance indices (Healey et al. 2005; Masek et al. 2008).

In this study we will present, evaluate and validate an already existing approach to monitor forest disturbances (Healey et al. 2005) and extend the analysis to evaluate grazing on high intensity grazing lands. We apply the approach to both Landsat and MODIS imagery for the North Island of New Zealand and validate the results based on high resolution OrbView and Ikonos imagery. We split the validation results by soil type and also evaluate the effect of different soil types with respect to grazing pressures. We provide a close-up study of one catchment in the Waikato region, which contains 34% of the national total dairy herds (DairyNZ 2013).

2. Study area

In this paper, we will first apply all methods to the entire North Island of New Zealand. The North Island of New Zealand has an approximate size of 115,000 km^2 (Fig. 1). Before human settlement, about 85% of the total land area of New Zealand was covered in primary forests (Kirschbaum et al. 2011). European settlers developed pastures on deforested land starting in the mid-1800s, at which point about half of the island was covered in grassland. As of 2012, the North Island still consisted of approximately 32% indigenous forest, and about 3.5% of the land area is low-producing grassland, which contains a mixture of exotic and indigenous grasses that are not grazed intensively. A little more than 46% of the land area of the North Island has been converted to high-producing grasslands, which are heavily grazed and typically fertilized and/or irrigated. About 12% of the North Island is used for plantation forestry. In all, forests and grasslands make up more than 93.4% of the North Island. The North Island of New Zealand has a warm temperate, maritime climate with mild temperatures and moderately high precipitation. The mean annual rainfall is about 1500 mm.

More than 60% of New Zealand's dairy cows are located on the North Island, and the greatest concentration of dairy herds are located in the Waikato region which supports 34% of New Zealand's dairy herds and 28% of its dairy cows. The Waikato region is the fourth largest region in the country, covering approximately 25,000 km^2. It is divided into 11 districts. In this study, we have selected Komakorau catchment in Waikato district (which is one of the districts in the Waikato region) for a close-up investigation. Komakorau catchment is an intensively managed catchment just north of Hamilton (Fig. 1) predominantly covered with high-producing grasslands. The Waikato region supports a total of 4042 herds for a total of 1.39 million cows. As such it is a very relevant region to study with respect to dairy grazing (DairyNZ 2014).

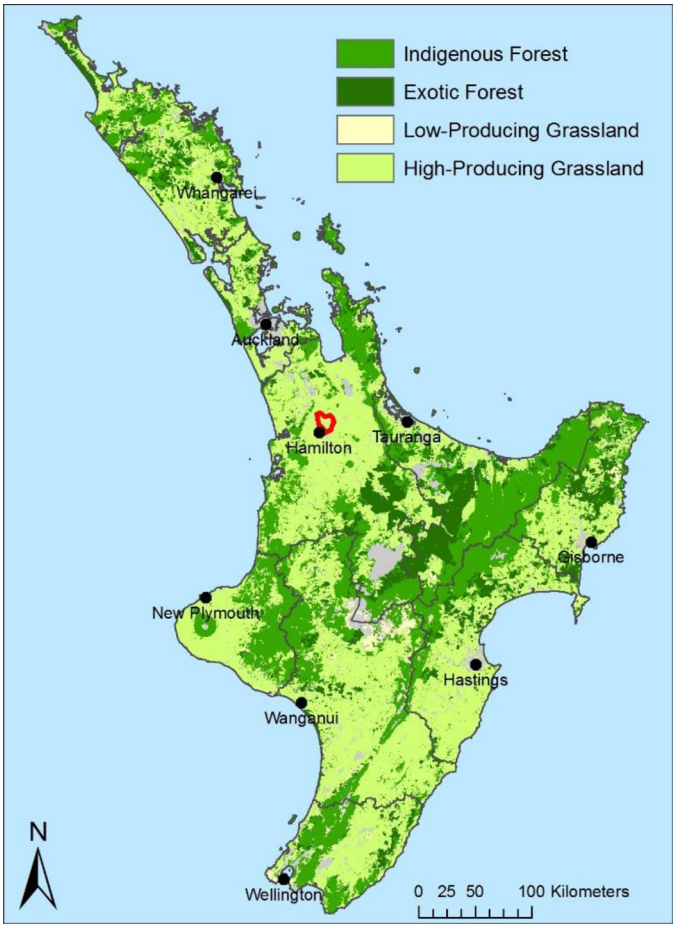

Fig. 1. Study region map with the four different land cover classes investigated. Grey areas have a different land cover classification and are not studied. The red area outlines the Komakorau catchment study area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Data

3.1. Climate data

We used long term gridded climate datasets from New Zealand's National Institute of Water and Atmospheric Research (NIWA; Tait and Turner, 2005) to create climate zone classifications. NIWA gridded these data and they were presented at 500 meter spatial resolution based on the interpolation of weather data from 1981 - 2010. Using median annual total rainfall, median annual average temperature, and median annual total sunshine hours, we divided the North Island into distinct climate zones (methods described in Section 4.1).

3.2. Land cover data

Disturbance data was standardized according to a land cover classification which comes from the New Zealand Land Cover Database (LCDB version 3.3) produced by Landcare Research and